POLYURETHANE FURNITURE - TOXIC GASES

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TABLE OF CONTENTS

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ABSTRACT

Fire has always been a killer. The media have concentrated on the sensational, and often tragic fires in public areas, department stores, Multi-storey Blocks of flats and Aircrafts.However the majority of fires, especially those that cause injury and death, occur in homes and a considerable percentage of these start in furniture that are made from polyurethanes

1. INTRODUCTION

Polyurethane Foam which comes under the general term, plastics was developed 40 years ago. There are many types of polyurethane foams and they fall into three major categories; rigid, semi-rigid, and flexible.

Because of their versatility, light weight, and cost advantages polyurethane foams have found their way into almost universal use. They are used extensively in the manufacture of upholstered furniture and mattresses, and has almost completely displaced traditional materials such as horse hair, cotton flock and latex foam in these applications. These advantages have led to a rapid market penetration, to a degree where flexible polyurethane foams have an estimated 95% of the furniture market and 80% of mattresses now consist partially or wholly of polyurethane foam

Polyurethane foam is used as a fabric-covered cushioning material in normal wood or metal-framed furniture and internal cushioning in mattresses. A typical 3-piece, 5-seater lounge suite may contain as much as 25kg of polyurethane foam. In addition to household items, polyurethane is now widely used for automotive seating. Industrial applications include thermal insulation, acoustic insulation and packaging protection.

However there is one major disadvantage, a high flammability. Not only do these foams ignite readily, but once ignited flame spread is rapid and large quantities of poisonous gases such as hydrogen cyanide and carbon monoxide together with dense black smoke are emitted.

2. THE FLAMMABILITY OF POLYURETHANE FURNITURE

2.1 Introduction

Over the past 10 or 15 years there has been a frightening change in the pattern of some types of fire. The main reason for this has been the changes in the manufacture and the design of furniture, particularly the introduction of polyurethane foams.

Polyurethane foams has several advantages such as: good ageing resistance, resists both mould growth and vermin, has good cushioning properties, are good light-weight insulators, are non-toxic to ingestion and skin contact, and are easy to shape and stretch into any type of furniture or bedding constructions. Despite all these advantages, many people associate polyurethane foams with fire. [Woods,1982]

The widespread use of flexible polyurethane foam in furniture has generated considerable concern and research into the flammability of such furniture. Polyurethane foam is also widely used in bedding, primarily as mattresses and occasionally as blankets. Statistics on the causes of fires and the incidence of injuries and death as collected by the New Zealand Fire Service are shown in the table below :

Summary of fires involving furniture or bedding 1987-9

Year	Total fires	Fires involving furniture			Fires involving bedding		
		fires	injuries	deaths	fires	injuries	deaths
1987	4428	89	5	1	405	39	4
1988	4657	185	14	6	335	35	6
1989	4363	220	28	8	330	40	3

Source - New Zealand Fire Service

From these figures it can be seen that there are several deaths and many injuries each year in fires involving furniture and bedding. Often such fires are caused by smokers' materials igniting furniture or bedding.

The ease of ignition of uncovered foam and its rate of burning results, to a large extent, from the physical form of the foam. Polyurethane flexible foam , having low density and low volume thermal capacity combined with the low heat conductivity shows a rapid temperature rise when heated by a flame or radiant heat. Uncovered foam is, therefore, usually easy to ignite and the burning rate is very sensitive to the heat flux at its surface.

However, in practice, polyurethane foam is rarely used without a cover and most of the work is aimed at understanding, improving and standardising the fire performance of flexible polyurethane foam upholstery is done with covered cushions. [Woods, 1982]

2.2 Smouldering Ignition Of Polyurethane Upholstered Furniture

The most important ignition source in real fires is the smouldering cigarette. Mass-produced cigarettes are round and firm with good rolling properties and treated to make sure that it continues to smoulder, making it an excellent delayed fire causing device for both traditional and modern upholstered furniture and bedding. However, a smouldering cigarette simply laid on the surface of an uncovered polyurethane foam cushion will not ignite but usually burns out leaving a scorch mark.

The classical smouldering ignition of an upholstered chair is by a smouldering cigarette rolling into the thermally insulated crevice between the seat cushion and the chair back, where it sets up smouldering combustion in the cotton cover, with the production of considerable quantities of volatile combustion products. This type of smouldering combustion may continue for hours with the internal cushion temperatures over reaching 600 degrees centigrade, until sufficient convection air flow causes the chair to burst into flames. [Woods, 1982]

2.3 The Cigarette Smouldering Test

The smouldering test is done with a standard non-filter-tipped cigarette, placed in the crevice between the seat and back cushions, but left uncovered. If progressive smouldering or flaming combustion is not observed within one hour of the placement of the cigarette the test is repeated. Any observation of progressive smouldering or flaming combustion constitutes a failure of test. This is the description of the test to British Standard 5852: Part 1: 1979.

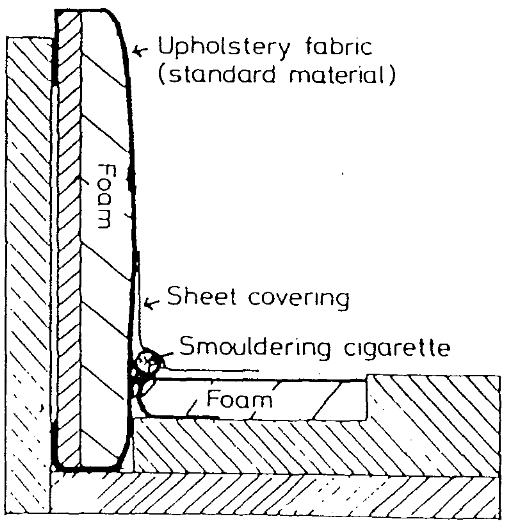

Figure 2.1. The smouldering test.

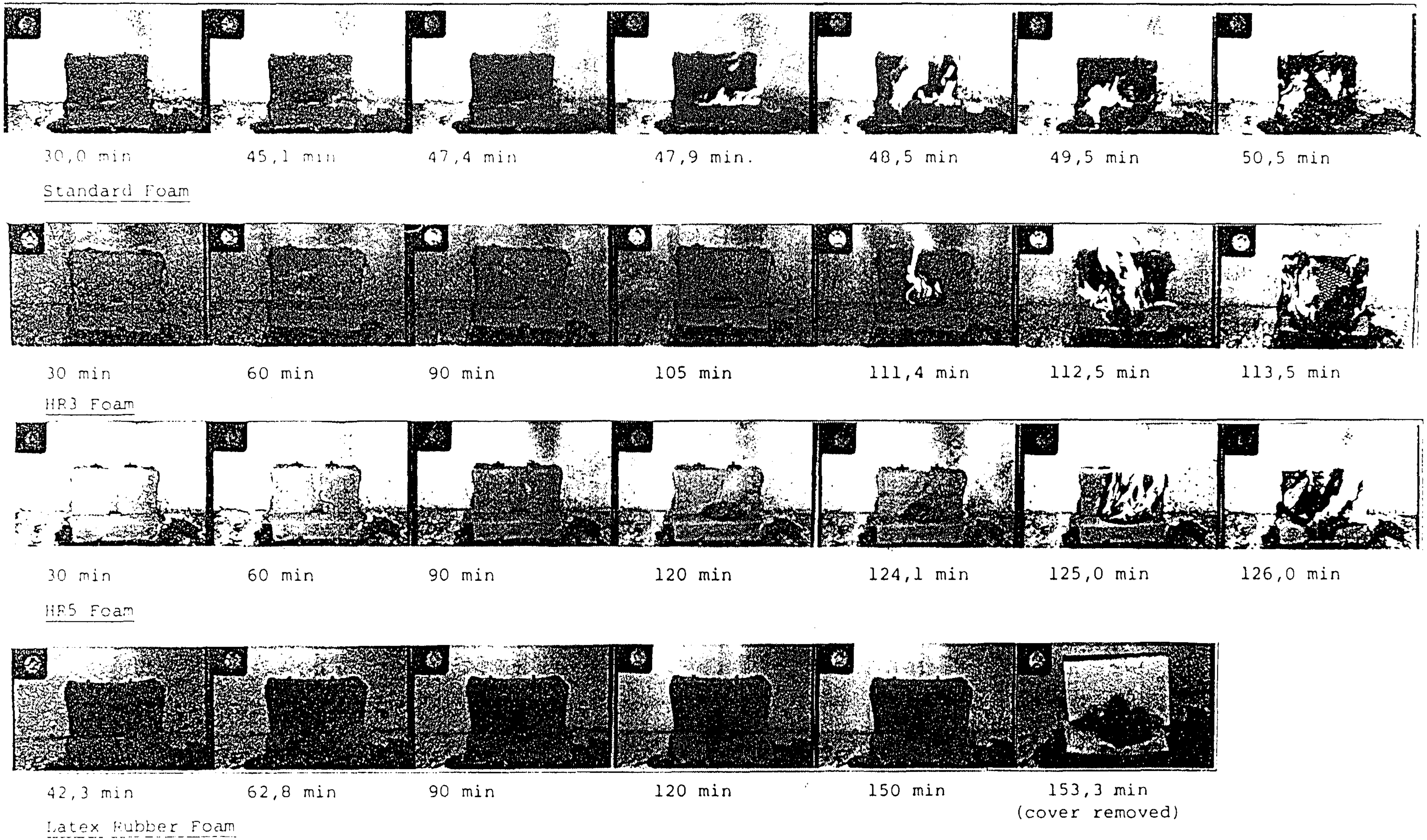

Figure 2·2 Results of Cigarette Ignition on Foams with Cotton Covers

A series of tests were carried out by Wool Research Organization of New Zealand (WRONZ) to the above standard. The aim of these tests was to investigate the ignitability of the more ignition - resistant, High-Resilience (HR) and Flame-Resistant (FR) grades of polyurethane foam. A cotton corduroy covering was used for the tests. The results are shown in the table below :

Cigarette Ignition Test Results - Cotton-covered-foam Chairs

Foam Type	Cigarette Test Result	Time to Flaming Combustion (min)
Standard	Fail	48
HR3	Fail	111
HR4	Pass	-
HR5	Fail	124
HR7	Pass	-
FR	Pass	-
Latex Rubber	Fail	Progressive smouldering combustion only

Two of the HR grades tested ignited, although both had a considerably longer time delay before flaming ignition occurred. See figure 2.2.

However, this longer time delay may be of doubtful benefit. Prior to flaming combustion occurring, a slow flameless combustion took place. In a real life situation this could easily go unnoticed, particularly in its early stages. It is often only several minutes before flaming combustion occurs that much smoke or smell is produced, thus giving some warning of danger. In each case, when flaming combustion did occur the flame spread was very rapid, probably because of the preheating effect of the smouldering combustion.

2.3.1 Significance Of The Results

It is possible for the situation to occur where a cigarette is dropped on a chair and smouldering combustion is unnoticed. The inhabitants of the house to go to bed unaware of the danger and up to two hours later a full-scale fire could occur in the room containing the upholstered furniture. In such a fire the time to flashover is likely to be very short suggesting escape difficulties because of flame and/or smoke and toxic gas hazards. [Ingham, 1981]

2.4 Open-Flame Ignition Of Upholstery

In the United States, the second largest cause of death is open-flame ignition of furnishings by matches. In the United Kingdom, open-flame ignition accounts for nearly a thousand deaths each year. Many of these result from children playing with matches, often with fatal results.

2.5 Match Ignition Laboratory Tests

Here tests are done using the assemblies of cover and filling described above for cigarette ignition, but attempting ignition with a standardised gas flame (as specified by BS5852:Part 1). A small flame, about 3.5cm long, is applied to the test assembly at the juncture of seat and back cushions for twenty seconds. The Standard requires that any flames, afterglow or smouldering, to cease within 120 seconds the removal of the flame. Otherwise the test is considered a failure. [Woods, 1982]

2.6 The Rate Of Burning Of Polyurethane Furniture

2.6.1 House Fire Tests

Small scale tests such as those mentioned earlier limit the assessment of the overall dangers of flammable furniture. House fire test gives a more realistic and relevant results for parameters such as rate of flame spread, temperature levels, smoke emission, and toxic gas concentrations than small-scale simulations.

WRONZ conducted a full scale room fire test in two houses due for demolition. A room in the house was furnished with normal lounge furniture, including a polyurethane upholstered lounge suite. The furniture was ignited by dropping a burning match on the couch of the suite.

A photographic record of the progress of the first and the second house fires is shown in figures 2.3 and 2.4 respectively. In the first house fire, the flames reached a height of 0.5 metres, several centimetres above the top of the couch, 40 seconds after the match was placed on it. The spread of the fire from this point on was very rapid. Associated with the burning was a very rapid production of black smoke which built up as a dense layer at ceiling level. Most of the contents of the room had been consumed by the fire within about a minute. Very little structure remained after 30 minutes. Strong winds at the time may have assisted the spread of the fire through the house.

Similar observations were made for the second house in which the experimental fire was lit. [Ingham, 1981]

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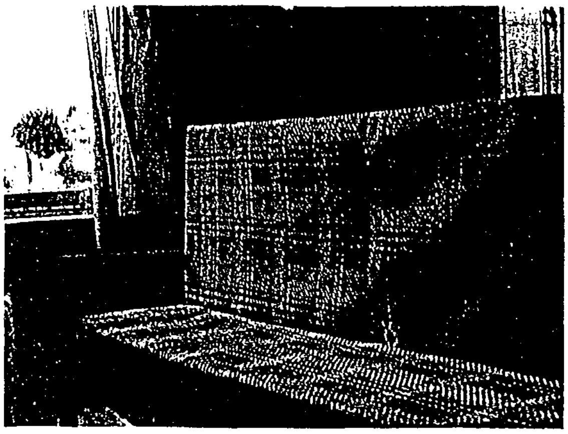
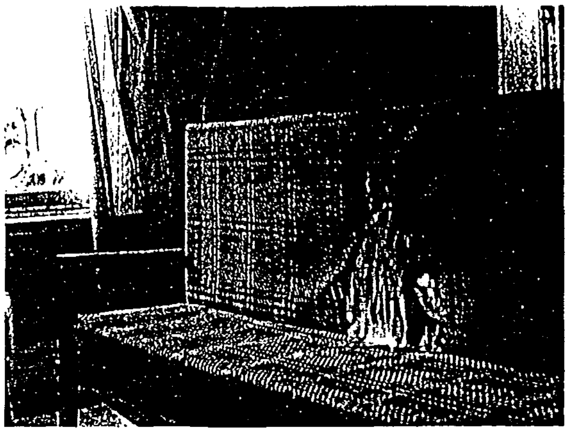


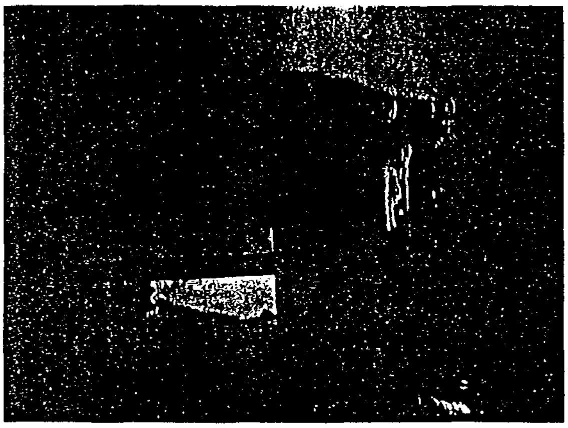
5 seconds



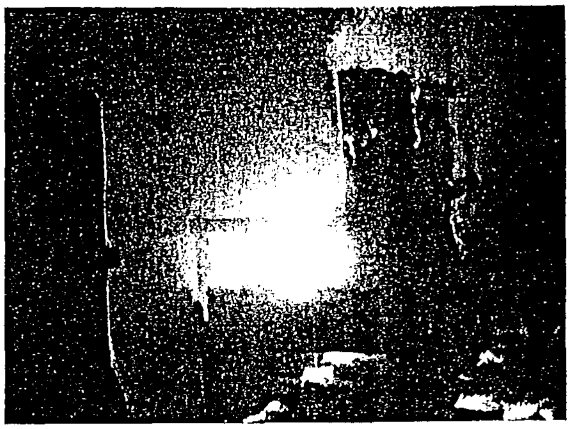
35 seconds

50 seconds

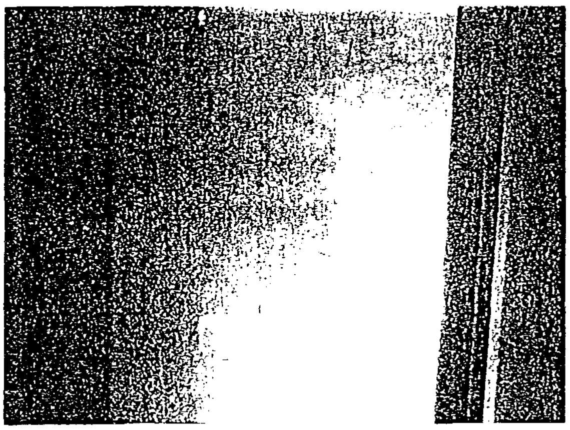
1 minute 25 seconds



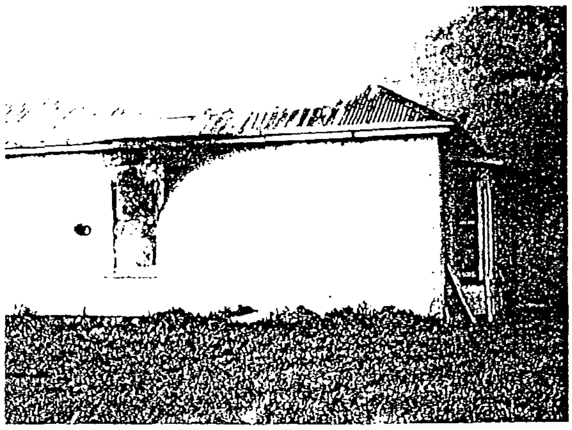
1 minute 40 seconds



2 minutes 30 seconds



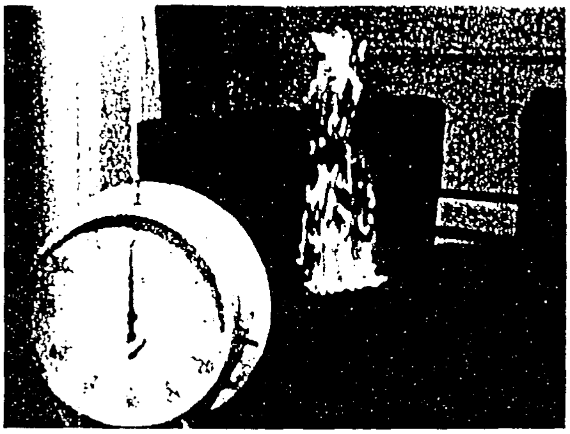
4 minutes 30 seconds (flashover point)



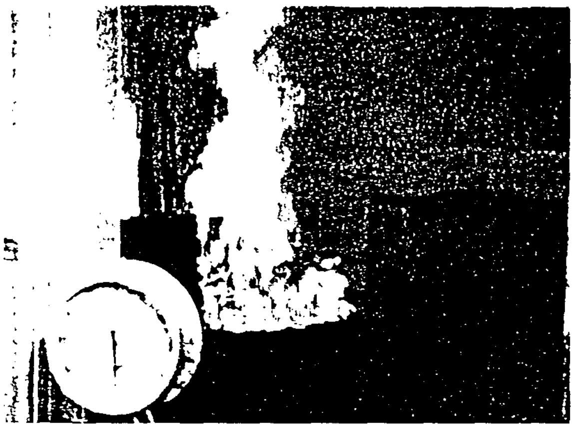
6 minutes 36 seconds

Fig. 2.3: Progress of the First House Fire

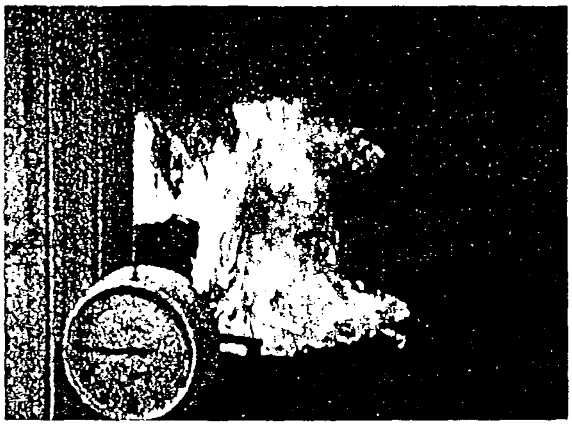
Ignition



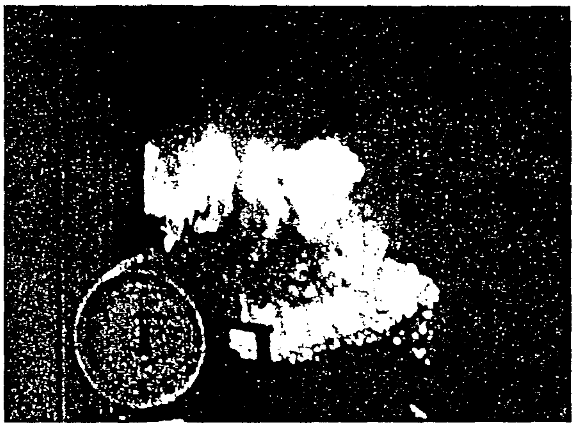
1 minute



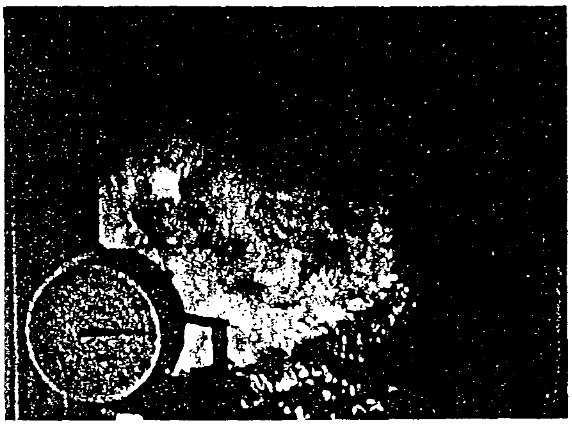
1 minute 30 seconds



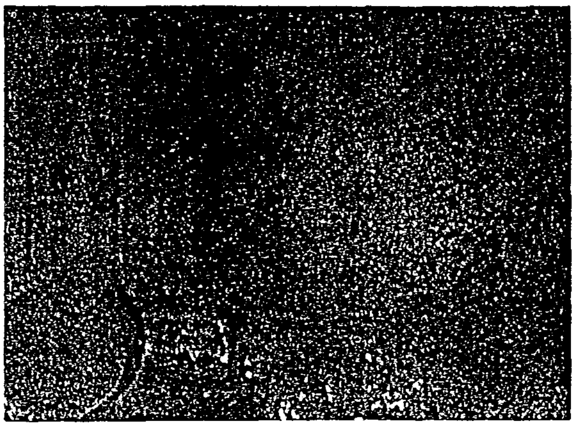
1 minute 45 seconds



2 minutes



2 minutes 15 seconds



2 minutes 45 seconds

3 minutes 15 seconds

Fig.2.4: Progress of the Second House Fire

3. TOXIC GAS PRODUCTION

Most of the deaths caused by fires result from the smoke and the toxic gaseous products of combustion. Overexposure to combustion gases in a fire situation is often the result of inadequate, obstructed or locked escape doors. The escape time is critical it may be as little as 1 or 2 minutes after the discovery of the fire.

The amount of smoke and the type and quantity of toxic gases produced by a burning polymer depend on the temperature attained in the fire and the availability of oxygen. The toxic gases produced in a polyurethane fire are as follows:

(1) Carbon Monoxide

Carbon monoxide is highly toxic. It is colourless, tasteless and almost odourless. It causes internal suffocation by combining with haemoglobin. The affinity of haemoglobin for carbon monoxide is about 300 times greater than that for oxygen. Concentrations of 8,000 parts per million (ppm) and higher causes immediate death.

(2) Carbon Dioxide

The important effect caused by carbon dioxide is that it stimulates breathing. Concentrations of 18,000 ppm increases that rate of breathing by 50% and this effect may obviously increase the hazard from carbon monoxide or other toxic gases present because the increased rate of breathing means faster inhaling of toxic gases.

(3) Hydrogen Cyanide

Hydrogen cyanide reacts with the ferric ion of oxide in the body and prevents the utilisation of oxygen. Concentrations above 280 ppm are immediately fatal

(4) Acrolein

Acrolein is an extremely irritant gas which causes intense irritations at levels from less than 1 part ppm and is lethal in a short time at levels over 10 ppm.

(5) Hydrogen Chloride

Hydrogen chloride is a severe irritant and is formed by the combustion of flexible polyurethane foams containing chlorinated flame retardants but the resulting levels are normally not hazardous.

The table below shows the statistics from a U.K dwelling of fatal fire casualties in 1976. It is evident from the table that most of the deaths resulted from smoke and toxic gases rather than from burns itself. This is especially true for upholstered furniture and bedding where polyurethane is extensively used.

Ref ?

U.K. DWELLING FIRE FATAL CASUALTIES 1976

Material first ignited	Cause of death		Residue	Total
	S&TG*	burns		
Upholstered furniture	58	25	4	87
Bedding	104	21	7	132
Carpets	8	2	2	12
Curtains	2	0	1	3
Clothing in wear	19	75	2	96
Textiles in use	191	123	16	330
Total in dwellings	400	236	54	690

* S&TG = smoke and toxic gases

The university of California conducted a toxicity test and obtained some data on several different materials. The aim was to compare the toxicity of polyurethane foam with that of natural products. The toxic gases emitted from 1 gram of each material was collected and the average time to death of four mice exposed to these gases were measured. The results are shown in the table below;

TOXICITY OF PYROLYSIS GASES FROM FLEXIBLE FOAM COMPARED WITH THOSE FROM NATURAL PRODUCTS

ref ?

Material	*Time to death (min)*	*Reference*
Flexible polyurethane foam (8 different samples)	19·31–22·38	632
Beechwood	13·82 ± 1·83	632
White pinewood	15·42 ± 0·90	632
Hardboard	15·90 ± 2·62	632
Cotton batting (California)	10·16 ± 1·57	642
Cotton batting (Louisiana)	9·66 ± 1·29	642
+ 10% boric acid (padded)	14·58 ± 1·06	642
+ 8% boric acid (vapour dep.)	11·20 ± 1·25	642
100% cotton woven cover	13·69 ± 0·27	670
100% rayon woven cover	14·01 ± 2·88	670

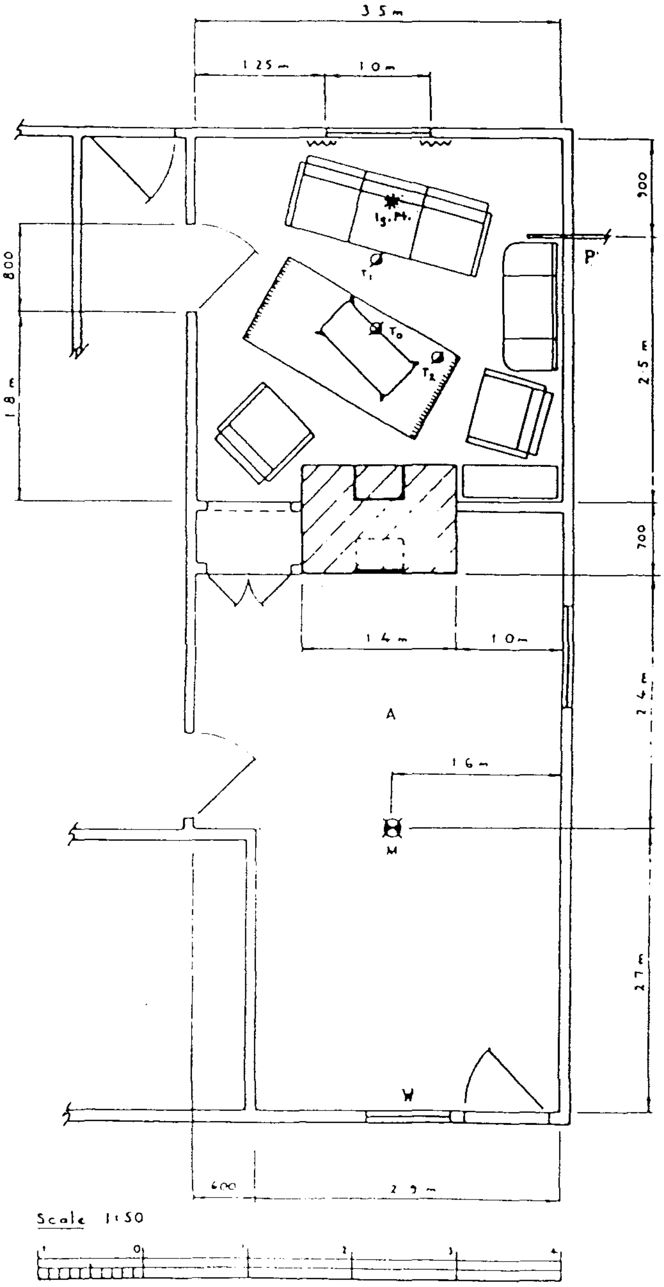
These findings reveal that for equal amounts of material tested polyurethane foams produce weaker concentrations of toxic gases then natural substances such as hardboard and cotton batting. It is apparent from the information available that the combustion of polyurethane foam does not yield an increased hazard from toxic combustion products as such but it is the high rate of burning that produces the toxic gases at alarming rates.

is this the same as 2.6.1 ?

4. EXPERIMENTAL CASE STUDY ON TOXIC GASES

The Wool Research Organisation of New Zealand (WRONZ) performed an experimental fire situation on a house situated in a residential area of Christchurch. The house was of timber-framed construction, with weatherboard cladding and a corrugated iron roof. It was generally in good condition and was estimated to be around 80 years old.

The fire was ignited in a room which was furnished with a lounge suite consisting of two chairs and one 3-seater couch, a coffee table, a sideboard, and a wooden cabinet.The cushioning in the chairs and couch were made from polyurethane foam. The arrangement of the furniture is shown in the diagram below,



Partial floor plan of the house, showing the rooms used for the fire and for monitoring

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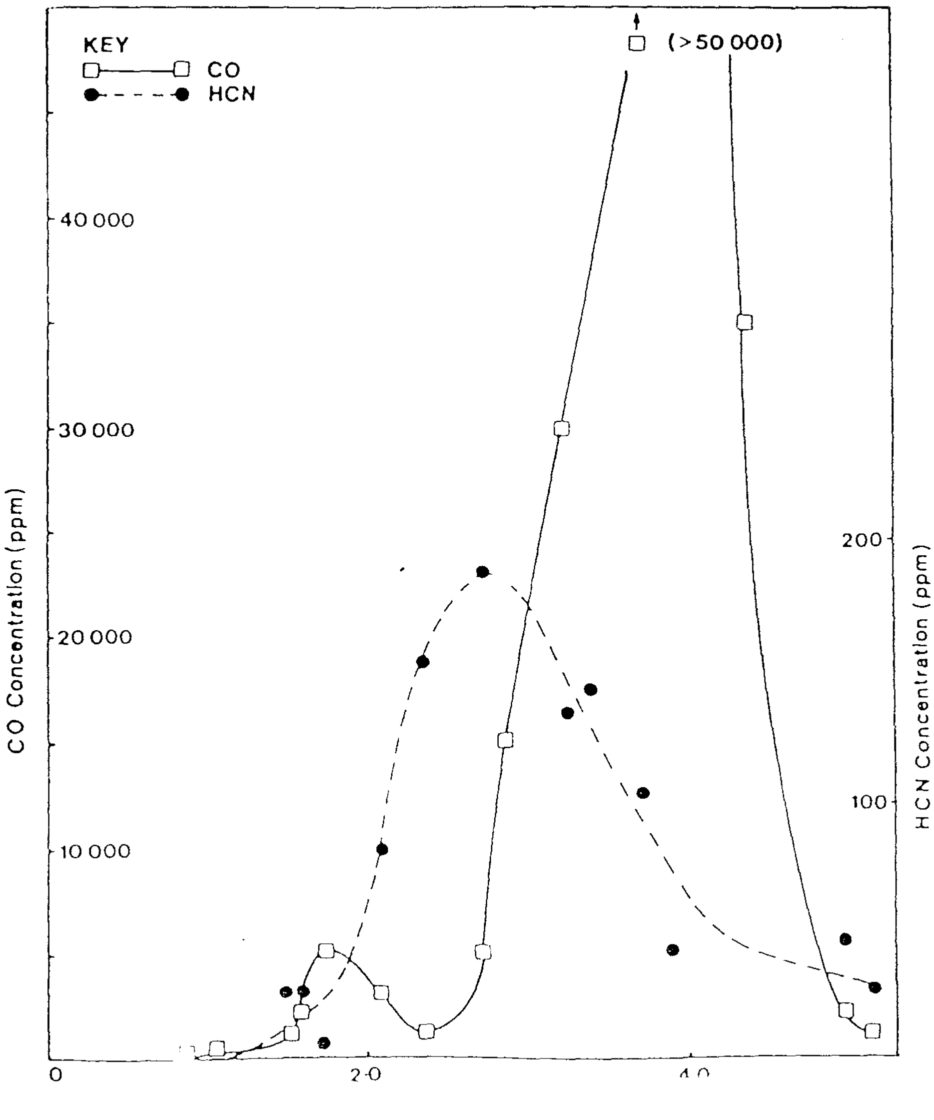
The levels of carbon monoxide and hydrogen cyanide were measured during the fire. A metal pipe was inserted into the room through a hole drilled in the wall from outside, as shown at P in the diagram so that samples of air could be pumped out of the room for testing.

The period of the fire , from ignition to when it was extinguished took 4 minutes and 30 seconds. The following observations were made at different times during the course of the fire:

flames touching the ceiling	1min	2sec
curtains burning	1min	30sec
flames droplets falling onto the floor	1min	40sec
window broken	2min	15sec
flashover	3min	30sec
fire extinguished	4min	30sec

The carbon monoxide and hydrogen cyanide levels during the fire are shown below,



The carbon monoxide levels reached 5,000 ppm at 1min 45sec, fell back to 1000 ppm at 2min 20sec, then climbed rapidly thereafter to peak at over 58,000 ppm at 3min 43sec. The reduction in carbon monoxide concentrations up to 2min 20sec and the subsequent rapid rise is likely to have been due to lack of oxygen to sustain the fire and a renewal of the supply when the window broke. Concentrations of 8,000 ppm or greater causes immediate death. This shows that at approximately 2min 45sec into the fire it was no longer safe for human occupation

The hydrogen cyanide levels were considerably lower in quantity than those of carbon monoxide, reaching a maximum of 184 ppm at 2min 43sec after ignition. The combustion of the polyurethane foam is likely to have been the main source of the hydrogen cyanide produced. Concentrations of 280 ppm or higher are immediately fatal but fatal poisonings can begin to occur at levels as low as 112 ppm. It is likely that the main role of cyanide in a fire lies in its additive contribution to the effects of carbon monoxide in producing asphyxia since the concentration of carbon monoxide far overshadows that of hydrogen cyanide once a fire is established.

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5. SAFETY PRECAUTIONS TO MINIMIZING FLAMMABILITY

As long as polyurethane furniture is being manufactured, the risk of it causing a fire is always present. These fires quickly gets out of control with very little time left for safe evacuation. Often if the flames do not kill then the toxic gases and the smoke does. Hence, fatalities results. In spite of this, a reduction in the manufacture and the use of polyurethane foam does not seem likely. This makes safety precautions to reduce the risk of ignition and to retard the rate of fire spread more important.

5.1 Practical Considerations

5.1.1 The Designing Of Upholstered Furniture

The Plastic Institute of Australia in a brochure for polyurethane foam manufacturers made the following suggestions in order to develop safer upholstery :

- to reduce ignition design a "cigarette gap" at the base of the chair back.
- reduce the vertical height of back cushions.
- make the angle of the back less vertical.
- reduce, if not eliminate, the 'chimney' at the back of some armchair constructions.
- reduce tension: the more a fabric is under tension, the greater the risk of its splitting open under heat, exposing the upholstery to fire
- fit resilient webbing horizontally in a chair to minimize rapid spread of flames. ['Choice',1982]

Note that all the above suggestions, except the first deals with minimizing and reducing the fire spread.

5.1.2 Influence Of Fabric Coverings

Polyurethane foam alone generally does not smoulder and needs at least a small flame to set it alight. It is the combination of the polyurethane foam and the covering material in upholstered furniture that creates the danger. The type of fabric covering plays an important role in determining the ignitability, smouldering characteristics, and the rate of flame spread.

The ideal covering material should retain some form and thickness when exposed to a source of ignition to prevent the penetration of flame and provide a barrier to oxygen entry.

Ignition studies of fabric-covered foams have shown that wool fabrics protects the foam from ignition by matches and hot-wire sources. Polyurethane foam mattresses are an extreme fire risk as they are so easily ignited and burn rapidly with evolution of thick toxic smoke and fumes. The danger is considerably reduced by the use of woollen overlay over the mattress (preferably covering its sides and ends), or wool ticking on the mattress, and to a lesser extent by wool blankets or a wool-filled duvet. Other coverings such as leather or vinyl would also generally not ignite from a cigarette. These coverings are also a protection against a small flame, but not against a fierce flame. [Ingham, 1984]

On the other hand, polyurethane foam covered with cotton, linen, or rayon do ignite from a cigarette and smoulder. (See fig. 2.2). Another modern combination - polyurethane foam covered with the synthetic furnishing fabric, polypropylene - will also smoulder.

5.1.3 The Use Of Fire-Retarded Foam

Foam manufacturers have attempted to reduce the flammability of polyurethanes foams, particularly by small ignition sources.The two common types of fire retarded foams are : High-Resilience (HR) and Flame-Retarded (FR), manufactured with the aid of chemical additives. Generally, HR flexible polyurethane foams are found to be more resistant to smouldering than conventional types as demonstrated by figure 2.2. In tests of bulk quantities of unmodified foam, FR foam and HR foam, it has been found that there is little correlation between small-scale and large-scale burning tests. In the small-scale tests there were some differences between the foams, but in large-scale tests all foams burned vigorously. [Ingham, 1979]

5.1.4 The Need Of Voluntary Controls

The Ministry of Consumer Affairs and the New Zealand Fire Service have considered the need for controls on the use of polyurethane foam in furniture and mattresses. It has suggested to have voluntary testing on all furniture supplied and offered for sale. The tests include ignitability of furniture by smokers' materials and also using the more intense ignition sources as described by the New Zealand Standard, NZS 8709 Part 1 (this is the modified version of the British Standard). There is an increasing awareness for the need of product safety standards for flammable polyurethane furniture as its demand increases around New Zealand.

How could controls be implemented?

To much detail on the page.

6. CONCLUSIONS

It is evident from the bulk of information available on polyurethanes that it is a potential fire hazard. Some forty years ago when it was developed, polyurethanes were thought to be the ideal alternative to the traditional products that were being used. But only recently has.it been fully investigated.

There are two distinct hazards from polyurethane upholstered furniture :

(a) Smouldering ignition - where the hazard is from toxic gases and smoke from the smouldering fire.

(b) Flaming ignition - where the very rapid spread of flames means that once ignition has occurred the escape time before flashover occurs would be very short.

The secret to flammability control with polyurethane foams is in the type of fabric covering. Tests have indicated that the best and the most fire retarded fabric coverings are wool products, leather, and vinyl. These coverings do not ignite either from a cigarette or a small flame source such as a match. On the other hand, the most hazardous fabric for smouldering ignition are cellulosic fabrics such as cotton, and for flaming ignition are polypropylene, acrylic fibre and nylon.

However, the toxic gas production problem is the most significant in fires involving polyurethane-upholstered furniture. All the tests conducted and the data available indicates that the high rates of production of toxic gases such as carbon monoxide and hydrogen cyanide are the major causes of fatalities in these fires. Hence showing that it is the toxic gases that often kills in such situations and not the flames.

Fires under normal dwelling circumstances can spread very rapidly so the question arises : Do the residential building codes provide adequate home fire protection considering that they have no relation to and can have no effect on the furnishings in the building? In houses that are fitted with smoke detectors, would such high concentrations of hydrogen cyanide and carbon monoxide that are being generated and convected in house fires only 20 or 30 seconds after the smoke detector sounds its alarm, gives the sleeping occupants a chance to wake up, orientate themselves, and escape? These questions are well worth thinking about.

Considering the large usage of polyurethane foams by the New Zealand upholstery industry, together with the increasing use of particularly flammable synthetic fibre fabrics it would be only logical to implement flammability controls, especially for furnishings in public buildings where the hazard is more acute and potentially dangerous.

ACKNOWLEDGEMENTS

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